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NUTRITIONAL COMPOSITION OF WATER HYACINTHS GROWN ON DOMESTIC SEWAGE

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A nutrient analysis of water hyacinths grown in sewage wastewaters was conducted. Crude protein averaged 32.9% dry weight in the leaves, where it was most concentrated. The amino acid content of water hyacinth leaves was found to compare favorably with that of soybean and cottonseed meal. The vitamin and mineral content of dried water hyacinths met or exceeded the FAO recommended daily allowance, in many cases. It is concluded that in favorable climatic zones, water hyacinths grown in enriched mediums, such as sewage lagoons, could potentially serve as a substantial dietary supplement or nutrient source.

The water hyacinth, *Eichhornia crassipes* (Mart.) Solms, has perhaps been the subject of more intensive study than any other aquatic plant in recent years. A native of South America, this floating aquatic species has adapted exceedingly well to almost every area into which it has been introduced. In the southern United States, it is the number-one aquatic plant pest species. Due to its vegetative reproduction and extremely high growth rate, water hyacinths spread rapidly, clogging drainage ditches, shading out other aquatic vegetation and interfering with shipping and recreation (Holm et al., 1969; Raynes, 1972). Much effort and many dollars have been devoted to the control of this prolific weed (Bates & Hentges, 1976).

In the last several years, many investigators have directed their research endeavors to the utilization of the water hyacinth. Several scientists (Cornwell et al., 1977; Miner et al., 1971; Rogers & Davis, 1972; Sheffield, 1967; Wolverton & McDonald, 1976c) have considered the water hyacinth as a potential biological agent for treating sewage wastewaters and feedlot operations. The water hyacinth is particularly well-suited for this purpose, because it is extremely productive (Westlake, 1963; Wolverton & McDonald, 1976c) and feeds directly from the water via its extensive root system. Wolverton and McDonald (1976c) reported growth rates as high as 17.5 metric tons of wet biomass per hectare per day (approximately 0.88 metric tons dry matter per hectare per day, based on an estimated 5% solids per wet weight) when water hyacinths are grown in domestic sewage lagoons during the warm summer months.

In order to maximize the efficiency of nutrient removal by water hyacinths, the plants should be periodically harvested as they become saturated with excess nutrients. Ideally, the harvested plant material should be utilized, in order to defray the costs of removal. Various investigators have proposed using harvested water hyacinths as food supplement both for cattle (Baldwin et al., 1974) and humans (Wolverton et al., 1976), as a soil additive (Gratch, 1965; Parra & Hortenstein, 1974; Wolverton & McDonald, 1976a), as a source of paper and fiber (Bagnall et al., 1974), and as an energy source (Wolverton & McDonald, 1976b; Wolverton et al., 1975). The use of water hyacinths as a food source appears most promising. Gosset and Norris (1971) have demonstrated a definite relationship between nutrient availability and the nitrogen and phosphorus content of water hyacinths. Haller and Sutton (1973) analyzed water hyacinths grown in nutrient solutions with different phosphorus concentrations and found that the phosphorus content of the plants increased as the phosphorus content of the

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TABLE I

NUTRIENT LOADING RATES OF SAMPLE SITES (BASED ON YEARLY AVERAGE NUTRIENT CONCENTRATIONS)

	5-Day biochemical oxygen demand		Total Kjeldahl nitrogen		Total phosphorus	
	kg/ha/day	lb/ac/day	kg/ha/day	lb/ac/day	kg/ha/day	lb/ac/day
Lucedale	57	52	9.8	9.0	2.4	2.2
Orange Grove	83	76	14.9	13.6	8.3	7.6
NSTL Lagoon #1	24	22	2.5	2.3	0.7	0.7
NSTL Lagoon #2	4	4	1.1	1.0	0.3	0.3

water increased up to a maximum level of 40 ppm phosphorus in the water. Because the nutrient composition of water hyacinths is generally proportional to the nutrient content of the medium in which the plants are grown, sewage-grown water hyacinths should be particularly high in protein and minerals.

Since 1975, NASA (Wolverton & McDonald, 1976c) has been experimenting with the use of water hyacinths as a biological treatment method for domestic wastewaters. In this paper, we present the result of nutrient analyses of water hyacinths grown on four experimental sewage lagoons in southern Mississippi. Most workers investigating nutrient contents of the water hyacinth have analyzed whole plant tissue. We have examined the relative nutrient contributions of the roots, stems, and leaves. Analyses for vitamins and minerals were also performed.

MATERIALS AND METHODS

The four sewage lagoons into which we have introduced water hyacinths are located in southern Mississippi. Two are located on NASA's National Space Technology Laboratories (NSTL), Bay St. Louis, and the other two serve small communities in the area. Nutrient loading rates are presented in Table I.

Plants were collected in late summer on the same date from four domestic sewage lagoons that had supported the growth of water hyacinths since spring. The plants were thoroughly washed with tap water. The leaves, stems and roots were separated from half the plants; the remainder of the plants were left intact. All samples were dried in an oven at 100°C for 24 hours and ground to an even consistency in a blender. The plant powder was analyzed for vitamins, minerals, amino acids, ash, fiber, and fat.

Analyses for vitamins, sulfur, total Kjeldahl nitrogen, total phosphorus, crude fiber, ether extract (fat), pepsin digestibility, and xanthophyll were done by Research 900, St. Louis, Missouri.

The crude protein was calculated as Kjeldahl nitrogen × 6.25.

The mineral analyses were determined by atomic absorption/flame emission with an IL 253 spectrophotometer following digestion of 0.50 g of plant material in 10 ml concentrated nitric acid and 2 ml 30% hydrogen peroxide. A blank was also analyzed for background correction.

Five-day biochemical oxygen demand (BOD_5), total Kjeldahl nitrogen (TKN), and total phosphorus analyses of the influent wastewater were performed according to Standard Methods (Franson et al., 1971). To determine the average nutrient loading rates, two grab samples per week were collected from the lagoon influent. The samples were collected for a period of one year from NSTL Lagoons 1 and 2 and over a six-month period from the other two lagoons.

TABLE II

COMPOSITION (PERCENT OF DRY WEIGHT) OF WHOLE PLANTS FROM FOUR LOCATIONS

Location	Crude protein	Fat	Fiber	Ash	Kjeldahl nitrogen	Phosphorus
Lucedale	22.3	2.04	19.5	15.1	3.56	0.89
Orange Grove	23.4	2.20	17.1	20.4	3.74	0.85
NSTL Lagoon #1	17.1	1.59	18.6	11.1	2.73	0.45
NSTL Lagoon #2	9.7	1.68	19.2	19.9	1.56	0.31

RESULTS AND DISCUSSION

Gross composition

As shown in Table II, whole plants from different sampling locations were found to contain fairly constant amounts of fat, fiber and ash; findings for these constituents were quite comparable with those reported by other investigators (Boyd, 1970; Parra & Hortenstein, 1974). Phosphorus content and crude protein, on the other hand, were found to vary considerably among the sampling sites. This is again consistent with the findings of other authors. Boyd (1970) noted that the protein content of water hyacinths declined with plant age and varied greatly among plants taken from different locations, in general reflecting the nutrient content of the waters in which they are grown. Gosset and Norris (1971) also found that both the nitrogen and the phosphorus content of water hyacinths increased with increasing concentrations of these nutrients in the culture solution. Our results corroborate these findings. Inspection of Tables I and II reveals a direct correlation between nutrient loading rate and crude protein content of the water hyacinths; that is, plants grown in lagoons with higher loading rates contain proportionally greater amounts of crude protein. At the highest nutrient loading rates, the difference in percent crude protein is less pronounced (compare, for

TABLE III

AMINO ACID PROFILE OF THE LEAVES AND STEMS OF WATER HYACINTHS COLLECTED AT LUCEDALE (G/100 G) DRY WEIGHT

Amino acid	Leaves	Stems
Aspartic	3.77	5.71
Glutamic	3.45	1.93
Alanine	1.94	0.67
Isoleucine	1.46	0.54
Phenylalanine	1.70	0.59
Ammonia	0.70	0.94
Threonine	1.36	0.54
Proline	1.88	0.62
Valine	1.74	0.58
Leucine	2.59	0.85
Histidine	0.69	0.23
Arginine	1.64	0.50
Serine	1.28	0.50
Glycine	1.61	0.59
Methionine	0.44	0.14
Tyrosine	1.06	0.37
Lysine	1.78	0.54
Cysteine	0.409	0.122
Tryptophan	0.309	0.167

TABLE IV

AMINO ACID COMPOSITION OF GRAIN PROTEIN COMPARED TO DRIED WATER HYACINTH LEAVES

	FAO reference pattern*	Grams/100 g protein					Water hyacinth leaves grown in human waste
		Corn	Rice	Oats	Wheat	Sorghum	
Lysine	4.2	0.8	3.5	4.0	2.6	1.8	5.7
Methionine + Cysteine	2.2	3.6	3.4	4.8	3.6	3.0	2.7
Threonine	2.8	4.1	3.3	3.6	3.0	3.6	4.3
Isoleucine	4.2	6.4	4.5	4.0	3.4	4.5	4.7
Leucine	4.8	15.0	8.0	7.1	6.8	11.6	8.3
Valine	4.2	5.3	5.4	5.1	4.6	5.4	5.6
Phenylalanine + Tryosine	5.6	13.1	10.3	8.4	7.6	5.2	8.8
Tryptophan	1.4		0.6	0.9	1.1	0.8	1.0
Histidine			2.2	2.2	2.3	2.0	2.2
Arginine			7.8	6.1	4.7	3.4	5.2

* Burton, B. T. 1976. Human Nutrition. McGraw-Hill Book Co., New York, p. 162.

example, Lucedale with Orange Grove, Tables I & II), indicating that plant protein is reaching a maximum level.

One reason that water hyacinths are so effective at removing excess nutrients is that they exhibit luxury consumption, particularly of phosphorus. That is, they will absorb more of this nutrient than they can utilize for growth. (Excess phosphorus is stored within the plant tissue.) In a study concerning the effects of high phosphorus concentration on growth of the water hyacinth, Haller and Sutton (1973) found that this plant can absorb roughly four times more phosphorus than

TABLE V

AMINO ACID COMPOSITION OF COTTONSEED MEAL AND SOYBEAN MEAL AS COMPARED TO DRIED WATER HYACINTH LEAVES COLLECTED FROM LUCEDALE (CONCENTRATION, G/100 G CRUDE PROTEIN)

Amino acid	Cottonseed meal*	Soybean meal*	Water hyacinth leaves
Lysine[b]	5.40	6.49	5.68
Histidine	2.16	2.63	2.20
Arginine	5.17	6.98	5.23
Aspartic	19.22	12.18	12.03
Threonine[b]	4.86	4.26	4.34
Serine	4.94	5.51	4.08
Glutamic	13.66	19.36	11.01
Proline	5.02	5.29	6.00
Glycine	5.56	4.48	5.14
Alanine	6.33	4.58	6.19
Valine[b]	5.48	4.80	5.55
Methionine[b]	1.31	1.37	1.40
Isoleucine[b]	4.40	4.90	4.66
Leucine[b]	7.80	7.98	8.26
Tyrosine	3.55	3.94	3.38
Phenylalanine[b]	5.10	5.37	5.42
Tryptophan[b]			0.99
Crude protein (%)	39.1	44.5	31.3

* Cottonseed meal and soybean meal analysis supplied by Mississippi State University.
[b] Essential amino acids.

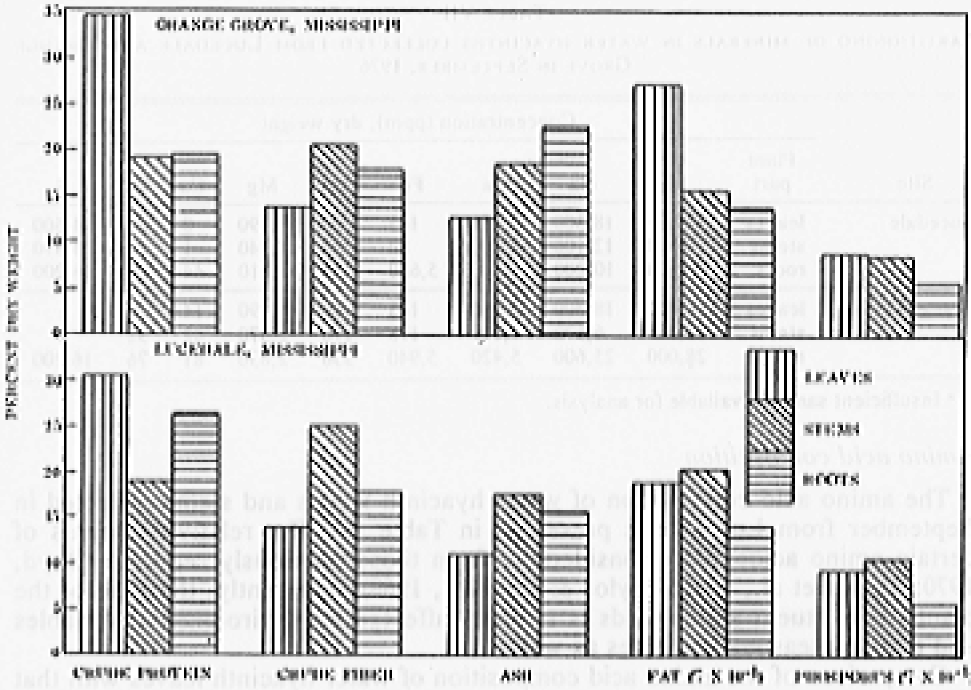

FIG. 1. Partitioning of nutrients in sewage-grown water hyacinths from two locations.

other plants which have been previously studied. These authors found that, at moderate phosphorus concentrations (5–10 mg/l), phosphorus within the plants was concentrated mostly in the leaves and stems, while at concentrations exceeding 20 mg/l, phosphorus was distributed more uniformly throughout the plant tissue. We also found roughly 66% more phosphorus in the leaves and stems than in the roots of the plants we sampled (Fig. 1); phosphorus concentration of the influent water ranged from 8.47–9.70 mg/l.

Other plant constituents also showed some partitioning within the plant tissue (Fig. 1). For example, leaves were found to contain the highest percentage of crude protein and the lowest percentage ash. The stems contained the largest portion of the plant fiber. Thus, the leaves of the water hyacinth would produce the greatest percent yield for protein extraction. However, this is somewhat misleading; because the stems comprise a much greater percentage of the total plant mass, they also contain a considerable amount of protein.

TABLE VI

MINERAL CONCENTRATION OF WHOLE WATER HYACINTH PLANTS COLLECTED FROM THE FOUR EXPERIMENTAL SITES

	ppm dry weight											
Location	Sr	Li	B	K	Na	Ca	Fe	Mn	Mg	Cu	Zn	S
Lucedale	146	3	3,980	27,800	18,600	7,450	1,581	86	1,683	10	25	5,810
Orange Grove	254	4	4,760	34,500	16,300	5,600	2,260	291	3,473	42	48	4,040
NSTL Lagoon #1				16,400	16,600	17,200	2,120	151	2,185	21	21	4,310
NSTL Lagoon #2	335	6	4,780	26,600	20,200	7,920	6,150	127	2,944	55	68	4,400

TABLE VII

PARTITIONING OF MINERALS IN WATER HYACINTHS COLLECTED FROM LUCEDALE AND ORANGE GROVE IN SEPTEMBER, 1976

Site	Plant part	Concentration (ppm), dry weight K	Na	Ca	Fe	Mn	Mg	Cu	Zn	S
Lucedale	leaves	36,000	18,300	7,560	143	69	8,490	8	23	4,500
	stems	27,300	12,100	8,760	82	88	1,540	1	15	3,370
	roots	30,300	10,200	6,860	5,630	41	1,810	44	63	16,200
Orange Grove	leaves	36,000	18,300	2,890	143	69	8,490	14	19	a
	stems	33,000	6,570	4,110	178	176	2,570	42	32	a
	roots	28,000	25,600	5,420	5,940	356	2,830	81	76	16,200

[a] Insufficient sample available for analysis.

Amino acid composition

The amino acid composition of water hyacinth leaves and stems collected in September from Lucedale is presented in Table III. The relative amounts of certain amino acids differ considerably from those previously reported (Boyd, 1970; Taylor et al., 1971; Taylor & Robbins, 1968); apparently, the ratio of the plant's constituent amino acids is strongly affected by environmental variables and perhaps seasonal variables as well.

Comparison of the amino acid composition of water hyacinth leaves with that of grain crop species and the FAO reference pattern (Table IV) reveals that the water hyacinth would make an excellent protein source and could be used as a dietary supplement to balance the amino acid intake in a predominantly grain diet. For example, water hyacinth could be used to supplement the lysine content of a corn diet for cattle or a rice diet for humans. A diet consisting mainly of wheat could be enriched in lysine, threonine, isoleucine, leucine, phenylalanine, tyrosine, valine, and arginine by the addition of water hyacinth protein. As shown in Table V, water hyacinth leaves compare favorably with the crude protein and amino acid content of high protein crops such as cottonseed and soybean.

Minerals and vitamins

The mineral composition of water hyacinths is presented in Tables VI and VII. As shown in Table VII, most minerals are present throughout the plant tissue.

TABLE VIII

MISCELLANEOUS VITAMINS AND NUTRIENT VALUES FOR WATER HYACINTH LEAVES FROM LUCEDALE SEWAGE LAGOON

Vitamins and nutrients	Concentration, dry weight
Thiamine HCl (B_1)	5.91 ppm
Riboflavin (B_2)	30.7 ppm
Vitamin E	206 ppm
Pyroxidine HCl (Vitamin B_6)	15.2 ppm
Vitamin A	2.45 ppm
Chemical niacin	79.4 ppm
Pantothenic acid	55.6 ppm
Pepsin digestibility	67.0%
Xanthophyll	485 ppm
Vitamin B_{12}	0.0126 ppm (roots: 0.682 ppm)

TABLE IX

UNITED STATES RECOMMENDED DAILY ALLOWANCES OF THE FOLLOWING VITAMINS AND MINERALS COMPARED TO DRIED WATER HYACINTH LEAVES GROWN IN DOMESTIC SEWAGE

Vitamin/mineral	U.S. recommended daily allowance	Content per 100 g dried water hyacinth leaves
Thiamine	1.5 mg	0.591 mg
Riboflavin	1.7 mg	3.07 mg
Niacin	20 mg	7.94 mg
Vitamin E	30 I.U.	20.6 I.U.
Pantothenic acid	10 mg	5.56 mg
Pyroxidine HCl (Vitamin B_6)	2 mg	1.52 mg
Vitamin B_{12}	6 μg	1.26 μg
Calcium	1 g	0.756 g
Iron	18 mg	14.3 mg
Phosphorus	1 g	0.927 g
Magnesium	400 mg	849 mg
Zinc	15 mg	2.3 mg
Copper	2 mg	0.8 mg
Sodium	0.2–4.4 g	1.83 g
Potassium	3.3 g	3.60 g
Sulfur	0.85 g	0.45 g

However, iron and, perhaps, copper and sulfur are concentrated in the roots, while magnesium appears to be concentrated in the leaf tissue. No toxic levels of lead, silver, cadmium or chromium were detected in the plant tissue. When detected at all, the amounts of these substances were no greater than those present in soybean and cottonseed meal.

The relatively high mineral content of the water hyacinth, comparable to that of many crop species, suggests that this plant could make a good soil additive as well as a dietary supplement. In a study comparing water hyacinth with commercial fertilizer, Parra and Hortenstein (1974) found that water hyacinth applications produced as good or better crop yields than did applications of commercial fertilizers for certain soil types. Basak (1948) found that the nutrient content of water hyacinth compost was approximately four times greater than that of farmyard manure and twice as great as compost prepared from town refuse and night soil. The mineral values of our sewage-grown hyacinths are similar to those reported by Parra and Hortenstein, except the Mississippi hyacinths contain slightly more sodium and considerably more calcium and copper than they reported.

The vitamin contents of sewage-grown water hyacinth leaves are presented in Table VIII. Vitamins may be even more concentrated in other plant parts. For example, the roots contain over 50 times the amount of vitamin B_{12} that is present in the leaves. A comparison of the content of selected vitamins and minerals in water hyacinths with that of the United States recommended daily allowance is shown in Table IX.

CONCLUSIONS

Inspection of Tables IV, V, and IX reveals that the water hyacinth could be an excellent source of proteins, vitamins, and minerals, and could be of particular value as a dietary supplement in countries where human diets are generally deficient in these nutrients. The high water content of *E. crassipes* (95%) makes utilization of this species difficult on a large-scale commercial basis. However, we feel that this fast-growing plant species would be beneficial to human diets on an individual basis, because less than 3 kg of harvested, fresh water hyacinth leaves could provide essentially all of the protein, minerals and vitamins required daily in the human diet. We are currently experimenting with low-cost harvesting and processing methods which should make the utilization of water hyacinth nutrients more feasible on a large-scale basis.

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